Supplementary Material

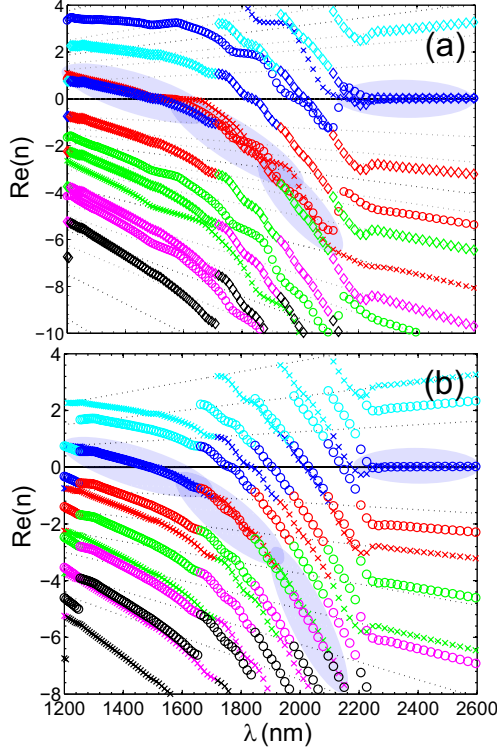

FIG. 1: Branches of the refractive index, Re(n) with $m =1$ (cyan), 0 (blue), -1 (red), -2 (green), -3 (magenta) and -4 (black). The cross, circle and diamond symbols in (a) represent Re(n) for 7, 11 and 19 layer strongly coupled fishnet structure, respectively. The cross and circular symbols in (b) represent the 19 and 27 layer strongly coupled fishnet structure, respectively. The shadow region shows where different branches overlap for 7, 11, 19 and 27 layers fishnet structures. The grey dotted lines show the branch boundaries which are given by $m\pi/kL$.

The effective retrieved parameter (ϵ, μ, n and z) of single layer and many layers of metamaterial can be obtained from the transmission T and reflection coefficient R. There is a need for T and R to be inverted. As was discussed in detail in the literature [10-13], one can invert T and R

$$z(\omega) = \pm\sqrt{\frac{(1+R)^2 - T^2}{(1-R)^2 + T^2}} \tag{1}$$

$$n(\omega) = \pm\frac{1}{kL}\arccos\left(\frac{1-R^2+T^2}{2T}\right) + m\frac{2\pi}{kL} \tag{2}$$

where L is the width of the homogeneous slab, and $m =$

±1, ±2, ... Note that both functions, $z(\omega)$ and $n(\omega)$, have multiple branches. The correct branch for $z(\omega)$ is chosen by imposing the physical requirement Re(z) ≥ 0 which is due to causality. The problem with the different branches of Re(n) can be solved by considering different lengths for L, and one has to choose the branches that overlap. Especially if one has many layers, then many branches exist and one has to be very careful to select the correct ones. For the strongly coupled layers that the results were presented in Fig. 4, we would like to discuss how these branches were selected. The unit cell size is called d_0 and it consists from metal-dielectric-metal and its width is $d_0 =160$nm.

In Fig. s1(a), we plot the branches and the retrieval results for 7 layers (width= $2d_0$), 11 layers (width= $3d_0$) and 19 layers (width= $5d_0$). Notice that the solutions for Re(n) overlap between 1200nm all the way to 2200nm and give negative values of Re(n). For $\lambda > 2200$ nm, Re(n) ≈ 0 and converges and the Im(n) ≈ 3 in this region. So for $\lambda > 2200$ nm the strongly coupled optical materials behave as a metal. In Fig. s1(b), we plot the branches and the retrieved result for 19 layers (width= $5d_0$) and 27 layers (width= $7d_0$) and one can see clearly that the convergence is much better for these larger systems. So we have solutions consisting of two discontinued region for the Re(n), Re(n) ≈ 0 for $\lambda > 2200$ nm and negative for 1500 nm< $\lambda < 2200$ nm.
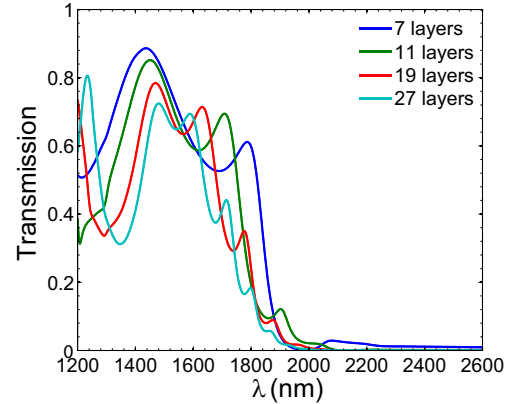

FIG. 2: Transmission spectra for 7, 11, 19 and 27 layers strongly coupled fishnet system.

In Fig. s2, we present the results for transmission, T, versus wavelength. Notice that for $\lambda > 2200$ nm, $T \approx 0$, which is a metallic behavior and this is the reason that Re(n) ≈ 0 and Im(n) ≈ 3 for $\lambda > 2200$ nm.